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CLOSED SHELLS OF NEUTRONS AND PROTONS IN THE ATOMIC NUCLEUS

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The assumption that protons and neutrons form closed shells within the nucleus was expressed long ago (cf 1-3). Recently a series of articles appeared (cf 4-6) in which the problem was discussed again. There it was proved that the total (increasing) number of protons in shells is 2, 8, 20, 50 and 82; and of neutrons, 2, 8, 20, 50, 82 and 126. These numbers were even referred to as magical. Usually it was assumed that the number of particles in the shells (of course only limits up to 82) and the order of succession of the shell are similar for both proton and neutron shells.

An empirical confirmation of the existence of closed shells of particles should be the very fact of the unusual stability of those nuclei in which every shell is complete. In order to prove that the so-called "magic" numbers of protons and neutrons really coincide with boundaries of shells, foreign literature quotes the most diverse data - namely, on isomerism, spins, magnetic and quadrupole moments. However they do not pay attention to a very important fact, namely the following.

In our work (cf 7) devoted to the problem of the periodization of elements on the basis of atomic structure, we pointed out that the absence in nature, as stable elements, of such elements as the 43rd and 61st could be explained by the existence, within the nucleus, of closed systems, of particles, containing /i.e. systems/ protons; with transition to the succeeding system after these systems have been filled, the bond energy of particles, just as in electron shells, decreases sharply, so sharply that this decrease, together with the increasing effect of electrostatic forces of repulsion which act between protons hinders the nucleus of the following element from forming.

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If we apply the same principle to the study of neutron shells, we find an essential significance in the fact that there are no stable nuclei with the number of neutrons equal to 19, 35, 39, 45, 61, 115, 123, and also with natural alpha-radioactivity and number of neutrons equal to 129 and 139 in nature. In most cases nuclei possessing such numbers of neutrons are characterized by artificial beta-radioactivity and therefore the probability of finding such neuclei in the stable state is very slight. Accordingly we may assume that, besides shells corresponding to certain "magic" numbers, nuclear shells with total (increasing) number of neutrons equal to 18, 34, 44, 60, 88, 114, 122, 128, and 138 also exist.

In Table 1, analogous to the periodic table of elements, which was presented in our previous work (a number of works on the problem of periodization of elements and atomic nuclei by Soviet writers have appeared (cf 7-11, and others), dashed lines designate the position of groups, absent in nature, of stable nuclei with the above-mentioned number of neutrons. The dotted lines designate the position of groups of nuclei with numbers of neutrons equal to 21, 51, 83; that is, those neutrons following after the "magic" numbers. The fact that nuclei with number of neutrons equal to 50 and 82 have closed neutron shells is confirmed particularly by the absence, as stable ones, of the heaviest strontium and barium isotopes.

Of great interest is the fact that some dashed lines corresponding to the completion of shells with total number of neutrons equal to 18, 34, 60, 88 and 114 (see Table 1) pass in places of "inflection" of periodic series of elements, in places where their "horizontal" parts pass over into "inclined" ones, that is, where the transition from those parts of periods in which the increase in the number of protons by unity is accompanied by the increase in the number of neutrons also by unity occurs, to those parts of periods where it (increase) is accompanied by the increase in the number of neutrons by two. Exactly similarly the numbers of neutrons equal to 50, 82, 138 are found in places of transition from one period to the other; that is, from "inclined" parts to "horizontal" ones. Thus, when the increase in the number of neutrons becomes more rapid, then a change of one shell by another also occurs, and this is observed in some cases even when the increase in the number of neutrons slows down.

This does not mean that the reverse is true; that is, that the transition from one shell to another always means a variation in the tempo of increase in the number of neutrons. As we see, the "inclined" parts of the 3rd and 6th periods contain several shells. It is possible that these are shells with approximately equal or close energy levels.

Relative to proton shells, the absence of a stable element following the completion of a shell can serve as a rather important indicator criterion of the existence of the end of the shell, as we saw, only in those two cases where the number of protons in the nucleus is 42 or 60. Along with this sign, which may be considered the most indicative of those recently utilized, essential significance relative to proton shells should also be attached to such indications, or signs, as the degree of abundance or distribution of elements in nature, which is probably a function of the stability of their nuclei. This criterion was already applied once (cf 4) to the proton shells of the elements Sn and Pb.

As is well known, the peaks on the curve describing the mean numbers of abundance (clark numbers) are occupied by elements with the atomic numbers: O 8, Si 14, Ca 20, Fe 26, Sr 38 (?), Sn 50, Ba 56, W 74, Pb 82 (the data on the abundance of strontium is questionable). Within this series we find most of the "magic" numbers.

Finally we obtain the following series of numbers which we may assume express the number of particles in shells (see Table 2).

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By comparing the data relating to the number of particles in nuclei that (i.e. nuclei) close their shells, we often find the same numbers of both protons and neutrons. It is particularly interesting that for both particles the number 60 is often encountered. Here, however, the numbers of particles, in each shell, of protons and neutrons, for the most part are quite different. This leads to the conclusion that, in contrast to the opinion predominant in foreign literature, the structure of proton and neutron shells cannot be considered identical. In one of the papers devoted to the problem on shells (cf 5) it is indicated that if no distinction is made between the structure of proton and neutron shells, then this problem may become a source of trouble for the theory and that particular attention should be paid to the study of the problem concerning the possibility of a peculiar structure of proton shells with number of particles beyond 60. As we shall see, even the problem concerning the structure of shells with a less number of protons deserves the same attentive study.

From our data some other conclusions pertaining to the modern theory of the structure of shells may be made. This data confirms the hypothesis concerning the existance, in nuclei, of shells filled by protons and neutrons. Quite different is the problem dealing with the theoretical basis for the number of particles in shells and with the order or succession of shells, as presently assumed (i.e. basis).

The theoretical explanation of "magic" numbers in foreign literature is based, as is well known, on the so-called model of Hartree, which assumes independent motion of particles in the nucleus; in this model the energy of the nucleus equals the sum of the proper (eigen) energies of the individual particles moving in a neutralized field. The number of particles in the individual shells is usually taken to be the same as in electron shells - that is, $2(2\ell + 1)$ - which gives series of numbers 2, 6, 10, 14, 18, 22, 26 etc, but the succession of nuclear shells is quite different from that for electron shells.

Here, however, as frequently indicated in literature, the theoretically computed number of particles in each shell and the total number of protons or neutrons in the nucleus do not correspond to the "magic" numbers. In order to obtain such a correspondence some writers (cf 1, 2, 5) exclude some of the theoretically-computed shells, and others (cf 6) change the theoretically-derived order of succession of some shells; the third (cf 4) besides changing the order of succession divide each shell (besides s-levels) into two parts, including into each of them particles with equal spin. By means of such rather artificial methods they succeed in finding a theoretical clarification of the "magic" numbers.

However, in relation to the numbers deduced by us (see Table 2) it turns out to be impossible. Of course we cannot ignore the fact that according to our data nearly all numbers corresponding to the formula $2(2\ell + 1)$ (namely 2, 6, 10, 14, 22 and 26) are to be found in neutron shells. Nevertheless a disparity remains between the empirical numbers of neutrons in other shells and the "modernized" theoretical calculations, and still stronger is the inadequacy of these calculations to explain the number of particles in proton shells.

Therefore, proceeding from our data we should reach the conclusion that the modern theory of the structure of shells should be reviewed.

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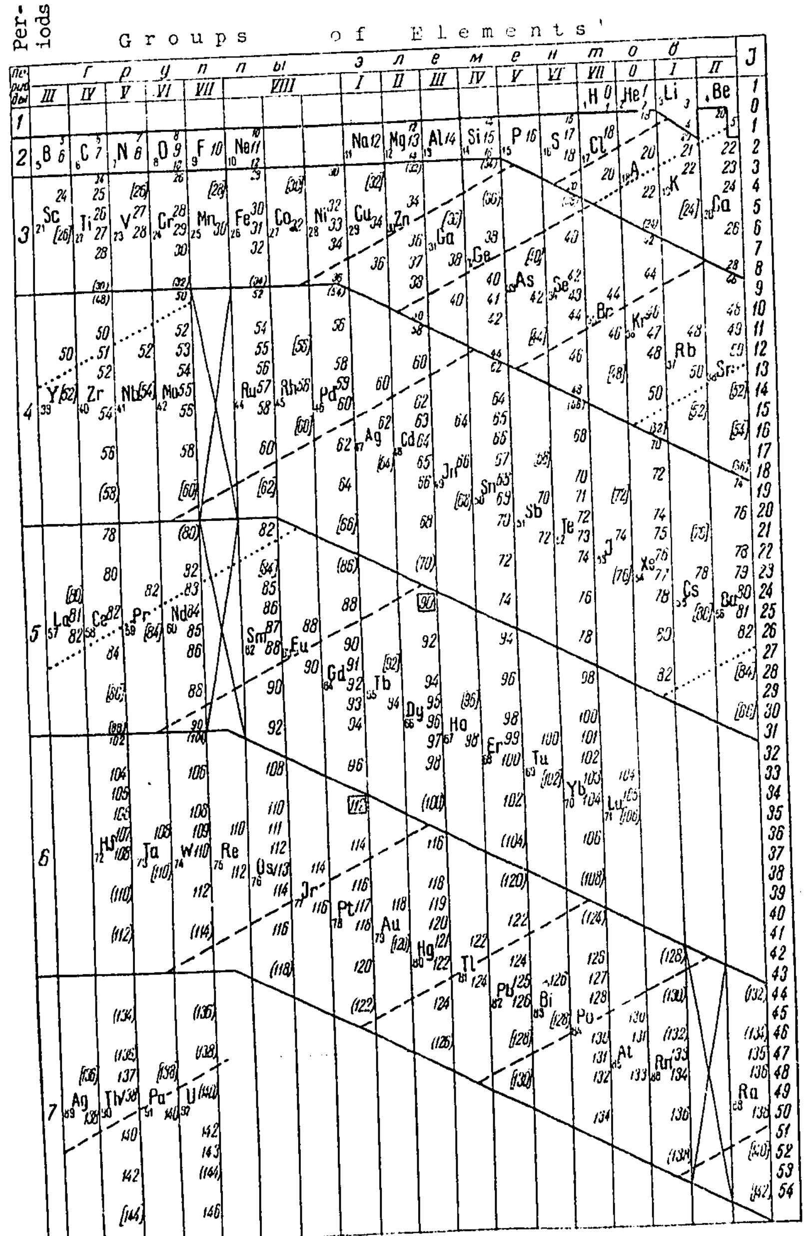
/Note: Below are Tables 1 and 2. Table 1 follows Table 2._7

TABLE 2

No. of protons in nuclei filling (i.e. protons) the proton shells	2	8	14	20	26		38?	42	50	56	60	74	82					
No. of neutrons in nuclei filling the neutron shells	2	8	18	20		34	38	44	50		60		82	88	114	122	128	138
No of protons in the shell	2	6	6	6	6		12	4	8	6	4	14	8					
No. of neutron in the shell	2	6	10	2		14	4	6	6		10		22	6	26	8	6	10

TABLE 1

Nuclei are designated by their number of neutrons. Nuclei with same isotopic number J are in horizontal lines; number corresponding to each horizontal line is in last column. Nuclei whose discovery can be expected are in parentheses; nuclei with small probability are in brackets. Those in squares are stable nuclei predicted in previous work (cf 7) and discovered after publication of our work; namely Dy^{156} and Pt^{190}.



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